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Sustainable production of Ebony : a threatened species

Literature review

Nina Pelletier

Bordeaux Sciences Agro, France

Nicklos Dudley

Hawaii Agriculture Research Center, USA

Executive Summary

Ebony trees (*Diospyros* species, *Ebenaceae*) are renowned worldwide and highly prized for their black, extremely dense wood. The grain of this wood is noted for its fine even texture with very high natural luster. It is considered a precious wood, and ranked among the world's finest woods. Further, many *Diospyros* species are also prized for their fruits, commonly known outside the tropics as persimmon.

Owing to African ebony's (*D.crassiflora*) exceeding slow growth rate and increasing demand and value in both the developed countries of the West and newly industrialized countries of Asia, namely China, it is increasingly overexploited in its native of the Congo Basin. It is listed as endangered species on the IUCN red list.

The silviculture of African ebony is largely incomplete and much information is lacking on its management. It is considered a long rotation species, requiring harvest cycles estimated to be at least 80 to 120 years. It is essentially a wild species and thought to be under extreme threat by some experts. Others assert that novel land management practices, such as agroforestry or mixed species planting, hold promise to conserve this species for future generations.

Tree improvement programs have significantly increased yields, wood quality, and condensed rotation age for a number of commercial forest tree species. This may be possible for *D. crassiflora*. Nevertheless, tree species with slow initial growth, including several of the *Diospyros spp.* are rarely utilized in modern plantations forestry because of silvicultural and economic constraints. When they are planted, it is generally as an enrichment species. When deployed as enrichment species, they are generally grown in either coffee or cacao agro-forestry systems. Potentially, ebony species could be intercropped with other high value hardwoods such as the rosewoods, or possibly *Acacia koa* (which also fix nitrogen). This may be a novel way to conserve and sustainably utilize this threatened species.

A strategy for ebony conservation and utilization may include elements of both in-situ and ex-situ genetic conservation. This will require the exploration, collection, testing, and finally the utilization of a range-wide collection of ebony (*D. crassiflora*) germplasm. This work is most successful when done within a consortium, composed of government, academic, and industry partners. Nevertheless, as a strategy for ebony conservation and utilization evolves, it will require a long-term commitment and substantial funding with an uncertain outcome.

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Introduction

Ebony (*Diospyros spp.)* wood is a highly-desired product utilized primarily for musical instruments. Blackwood of ebony has been used for centuries in musical instruments, especially for piano keys, guitar fingerboards and for wood carving figures. Musical instrument grade wood is produced by several other forest tree species, namely *Dalbergia.* However, the most desirable wood is from the genus *Diospyros*. *Diospyros* is a very large and widespread genus of trees and shrubs in the ebony family or Ebenaceae. Over 500 species have been described in total (IUCN-TRAFFIC; Lemmens et al., 2012). Among all these species, only ten have black heartwood when fully mature. They are exclusively tropical species (Normand, 1960). *Diospyros spp*. are exclusively harvested from native forest, and timber species of this genus are not known to be cultivated (Lemmens et al., 2012; Owona Ndongo et al., 2009; Development, Security and Cooperation, 2008). Despite the efforts made to enforce laws and protect these species, they are overexploited and often illegally cut in the remnant native forests of West Africa, Madagascar and Indonesia.

This review aims to gather all the available information both in French and English, about *Diospyros crassiflora*. The purpose is to know if this species can be managed as a plantation species to ensure a long-term, sustainable supply. Other species of ebony known for their black heartwood were also reviewed. These are Macassar (*Diospyros rumphii*, *Diospyros celebica*), Ceylon (*Diospyros ebenum*) and Malagasy ebonies (*Diospyros gracilipes, Diospyros perrieri, Diospyros platycalyx*).

A) General description of species

All the species described are members of the Ebenaceae family.

1) African ebony: *Diospyros crassiflora* (Hiern)

The wood of *D. crassiflora* (Hiern) is considered

to be the true African ebony. *D. crassiflora* is a dioecious, medium-sized tree up to 25 m tall with a cylindrical or fluted bole, branchless for up to 15 m, with above buttresses diameters up to 120 cm. *D. crassiflora* usually occurs as an isolated tree or in small groups of 2-3 trees. It is usually dominated by taller trees species, and is shade tolerant (Lemmens et al., 2012).

This species is registered on the IUCN red list of threatened species. Virtually all large trees of this species have been harvested for their beautiful wood. Small fragmented populations remain in remote areas (IUCN, 2015). In spite of this, *D. crassiflora* is still in high demand for its beautiful black wood. It has been exclusively harvested from native forest. Very little is known about its ecology and management owing to a paucity of research.

Diospyros crassiflora occurs from southern Nigeria east through Cameroon to the Central African Republic (CAR), and south to Gabon and Democratic Republic of Congo (DRC). It is found in lowland semi-deciduous and evergreen forests up to 1000 m (3280 ft) and usually avoids the most humid forest types (Lemmens et al., 2012). *D. crassiflora* appears to be widely adapted and has potential to be established outside its native range (Owona Ndongo, 2006).

2) Macassar ebony: *Diospyros rumphii* (Bakh), *Diospyros celebica* (Bakh), and *Diospyros discolor* (Willd), *Diospyros quayside* (Thw)

Macassar ebony is the commercial name for *Diospyros rumphii* (Bakh) and *Diospyros celebica* (Bakh)*. Diospyros discolor* (Wild) from Philippines and *Diospyros quayside* (Thw) have also been included in the Macassar group (Normand et al., 1960). But in this review, we will only deal with *Diospyros celebica* as it is the most studied species. This species can reach a height of 40 m with clear bole heights of 10-21 m. The diameter can reach 100 cm and large trees have buttresses of 3 m. The canopy is cylindrical to cone-shaped (Prajadinata et al., 2011). *D. celebica* is registered as a vulnerable species in the IUCN red list.

Geographically, *D. celebica* is distributed between 1° - 4° S and 119° - 120°. It is mainly found on the lowland tropical rain forests in Sulawesi (ITTO, 2014). It grows naturally in the humid area with a distinct seasonality (wet/dry), in rain forests and monsoon forests. It occurs from lowland to 540 m above sea level, with rainfall between 1230 to 2737 mm/year. The optimal rainfall range is from 2,000-2,500 mm/ year and temperatures between 22 and 28 °C (Hartati, 2007; Prajadinata, 2011).

3) Ceylon ebony: *Diospyros ebenum* (Koening)

Ceylon ebony (*Diospyros ebenum* (Koening)) is native to India and Sri Lanka. *D. ebenum* is a medium-sized tree up to 30 m tall and up to 90 cm in diameter. Its bole is straight, with buttresses up to 2 m high with a dense crown. Flowers are mostly male and bisexual (World Agroforestry Center). This wood species is not listed in the CITES Appendices, but is reported by the IUCN as being data deficient. It is noted as the ebony species of commerce in the international timber trade.

Diospyros ebenum is reported from South India and Malaya. It is also naturally found in Sulawesi, Moluccas and Nusa Tenggara (Indonesia). In India, it is a tree of the dry regions and occurs scattered in the dry evergreen forests of the Deccan and Carnatic. In Ceylon, it is found mostly in the dry zone, but extends into the intermediate zone and the wet -zone also (Koelmeyer, 1954; Kinho, 2011).

Diospyros ebenum prefers well drained soils with clay (Lemmens et Alo, 2012). According to Broun, the best ebony is found on rocky well-drained soil. Ebony is frequently found near watercourses, although it does not tolerate water-logged conditions (Koelmeyer, 1954).

A *D. ebenum* stand was established in the Arboretum of Manado Forestry Research Institute (Indonesia) and has a high survival rate (98%), indicating *D. ebenum* has good adaptability on outside its native range (Kinho, 2014).

4) Malagasy ebony: *Diospyros perrieri* (Hiern), *Diospyros platycalyx* (Hiern) and *Diospyros gracilipes* (Hiern)

There are several endemic *Diospyros* species in Madagascar. All the Malagasy species are registered on the CITES list. The species most known for their black wood are *Diospyros perrieri* (Hiern), *Diospyros platycalyx* (Hiern) and *Diospyros gracilipes* (Hiern) (Lemmens et al., 2012). They are small evergreen trees up to 15 m tall. The form of the tree is usually low-branching with main trunks up to 30-40 cm in diameter (Lemmens et al., 2012). *D. gracilipes* is particularly vulnerable due to exploitation and likely in decline. Surveys in southeast Madagascar determined the species had a density of 10-140 individuals per ha, and a low basal area (0.05-0.07m^2 per ha) and biovolume (0.11-0.14 m^3per ha) due to the scarcity or absence of large individuals in the sites (IUCN-TRAFFIC).

There is strong demand for all these species as they are highly valued for their black heartwood and wood with the excellent physical properties. Indeed, ebony has a high density, a high and homogeneous hardness and performs like an inert wood after drying. The density varies by species, but usually is higher than 1 000 kg/m^3 in most samples (Normand et al., 1960).

Diospyros gracilipes is widespread in the northern and eastern parts of Madagascar. It occurs mainly in humid evergreen forest, from sea-level up to 1350-1650 m altitude. The mean annual rainfall is 1000-2500 mm, with a dry season of 1-7 dry months, and the mean annual temperature is 20–24°C. It occurs on a variety of soils, from sandy to limestone and rocky soil (Lemmens et al., 2012).

B) Ebony potential as a plantation species: domestication of a wild species, opportunities and constraints

The potential for Africa's ebony is largely untested. It appears that ebony as genus is not widely planted in forestry tree plantations. Although, ebony enjoys precious wood status, there is little incentive to plant this species owing to its exceeding slow growth rates (See section E, Estimates of rotation age and growth). Despite a small number of experimental plantings, there is insufficient information to produce reliable estimates for any plantations of ebonies in tropical Africa, India, or Indonesia (Lemmens et al., 2012; Prajadinataet al., 2011; Peltier. R, pers. Comm)

One example of an experimental plantation is located at the arboretum of MBalmayo, Cameroon. This planting of *Diospyros crassiflora* was established in 1956. The stocking rate was 1,600 stem/ha at a spacing of 2.5m x 2.5m. The survival rate was reported to be excellent at approximately 90%, with a diameter growth rates comparable to the natural forest (Owonda Ndongo, 2006). Other details regarding genetic quality and management regimes were not reported (Note: See contact list: C. Mey).

Today, tree species with slow initial growth, including the *Diospyros spp.* are rarely used because of silvicultural, phytopathological and economic constraints (Bertault et al., 1995). When they are planted, it is generally as enrichment species (Prajadinata, 2011).

Essentially, all the timber ebonies (*D.crassiflora*, *D. ebenum*, *D. celebica*, etc.) are wild species. Through domestication, there may be considerable potential for improving the growth, yield, and wood quality of future plantings though careful selection and breeding.

Interestingly, most of the examples of cultivation of Diospyros species are for fruit production, as timber is a secondary long-term product (Leakey and Akinnifesi, 2008).

One of the most highly commercialized fruits of the *Diospyros* genus is the persimmon, or kaki, which comes from *Diospyros kaki* (Thunb). In Africa, *Diospyros mespiliformis* (Hochst) is often preserved in the garden for its fruits. Selection of Diospyros species such as *D. crassiflora* for both fruits and wood may emerge as a strategy for sustainable production and conservation.

Agroforestry systems are worth highlighting in that this land management practice provides habitat and biodiversity refuge for primary and secondary forest tree species including

increasingly threatened species such as *Diospyros spp.* (Gockowski et al., 2004; Daniels, 2006).

Further, fruit production could provide a necessary influx of income for viable domestication of this very slow growing species. Indeed, fruits could be harvested in the years that trees are growing before they reach a harvestable size for timber (Styslinger, 2010). An example of this is the fruity pulp of *D. crassiflora,* which is eaten and the seeds are said to have aphrodisiac power in Cameroon, according to the Messondo pygmies (C. Mey pers. comm.).

Although *D. crassiflora* is occasionally found in agroforestry systems, it is rarely utilized owing to its slow growth rate and lack of selected cultivars for fruit or wood production. There is a preference for other fruit tree species which are faster growing, or have more desirable fruit from a farmer's perspective (Leakey and Akinnifesi, 2008). Among the other *Diospyros species, D. mespiliformis* (Jackal berry, or African persimmon) is best known and most developed. It is prized for its fruit, and its wood has at times been substituted for *D. crassiflora*, is considered inferior (Obeng, 2010).

Finally, the World Agroforestry International Center for Research in Agroforestry (ICRAF) has on-going project for domestication of indigenous fruit trees and other non-timber forest products in West and Central Africa (Congo Basin). It is based in Yaounde, Cameroon. In addition, CIRAD and ENEF (Ecole nationale des eaux et forêts) of MBalmayo, Cameroon have wild fruit tree domestication initiatives.

C) Nursery techniques for propagation

1) Significance of seed germplasm

Seeds are an important starting point for propagation of many species of the *Diospyros* genus. In many cases, the use of seeds as propagules is considered the easiest, cheapest and most common means for timber tree species (Akinnifesi et al., 2004). The use of seeds further enables capturing naturally occurring genetic variation and this allows for selection of superior trees within a large population (White et al., 2007). Finally, seeds are the most reliable and widely used method for ex situ genetic conservation.

2) Collection of plant material

The genetic quality of tree germplasm, seeds, seedlings and clones is a key input in determining the potential success of any forestry endeavor. A number of common points need to be considered in any collection effort. Before commencing, a sound strategy for sampling should be (why, when, with whom, legal requirements) devised. Documentation of the collection is required for future reference, as sample material may still be in use many years from now. After collection, germplasm must be processed and stored properly.

Seed collection efforts should attempt to capture the available genetic variation with sampling (seed collection) the remnant populations of *D. crassiflora* across its native range (White et al., 2007). As little is known about patterns of genetic variation in this species, first stage sampling can be done utilizing a fairly coarse grid pattern, collecting at widely separated intervals following environmental gradients (Palmberg, 1980).

Seed collections may either be random (systematic), or targeted. A range wide, random systematic approach allows for the full evaluation of the species' genetic potential, while a targeted sampling may allow for genetic gain, through superior genotype capture. Targeted collections, however, often require more resources and expected gains may not materialize.

Random systematic sampling involves collection from at least 30 well-spaced individual mother trees throughout the species native range. This will ensure the genetic base has been maximized and the risk of inbreeding depression has been limited.

Targeted sampling attempts to capture germplasm from phenotypically superior trees for testing and use. This method involves extra time and energy in selecting and collecting from potentially superior trees. Success depends on heritability of the traits being selected for.

Alternatively, vegetative, or clonal collection has been applied when significant genetic gain through 'true-to-type' cloning is anticipated. However, vegetative sampling and subsequent multiplication require many more resources and expertise than seed collection.

Nevertheless, vegetative propagation offers the opportunity to categorize and archive mother trees with desirable wood quality. In the long run, this methodology could potentially aid in fast tracking the domestication process and save many years of selection and classical breeding.

Genetic diversity is generally largest in areas which are optimal for the development of the species in question. However, at the limits of the ecological range, outlying populations of the species may be exposed to extremes of temperature, rainfall or other edaphic conditions. Such provenances may possess morphological and physiological characteristics which are of great potential for specific environments. For this reason, it is particularly important these marginal and outlying populations are included in the collections (Turnbull, 1978).

Seed collected from wild populations will form the base population for further conservation and utilization efforts. The number of trees recommended to be sampled and collected from, is a minimum 25 individuals per stand and usually ranges from 100 to 1000 individual families (Palmberg, 1980). Finally, the inaccessibility of remaining natural ebony stands may significantly limit this effort.

The timing of seed collection is important to coincide with the ripening of the tree's fruits. Cameroon flowering of trees has been recorded from February to May for *D. crassiflora* with

fruits ripening about 6 months after. There are about 10 seeds per fruit. Seeds are oblong, up to 5 cm × 2 cm × 1.5 cm, and glossy brown to black in color (Lemmens et al., 2012).

Finally, the goal is to capture and maintain for the long term, a broad-based genetic resource available for future conservation and utilization efforts (Zobel and Talbert, 1984; White et al., 2007). The sampling strategy for these conservation efforts must ensure the greatest amount of within-population genetic variation is conserved in a limited number of individuals (Eldridge et al., 1993). By its very nature, sampling only captures parts of the population, and ex situ conservation is more prone than *in situ* conservation to go wrong. In situ conservation seeks to maintain gene pools by conserving entire populations together within their local environment in ecosystems large enough to be self-perpetuating (Soerianegara, 1967).

3) Aspects of forest tree seedling production

Since no specific seedling management data on *D. crassiflora* was found, we hypothesize that data on the other species presented could be applied and provide guidance for *D. crassiflora* seedling management.

D. celebica starts flowering and fruiting at age 5-7 years. Fruits are collected from the tree by climbing or are collected on nets so that they will not drop to the forest floor. Collection from the forest floor is avoided because seeds quickly deteriorate, and are attacked by the fungus *Peniulliopsis clavariaeformis*. Each fruit contains 3-11 seed. There are about 800-1100 seed per kilogram.

Seedling quality has two main aspects, the genetic quality of the seed and the physical condition of the planting material immediately prior to planting in the field. The genetic aspects were discussed in the previous section.

In general, high quality seedlings are disease free with sturdy stems and a fibrous root system without deformities and balance between the roots and shoot of the seeding. They have been conditioned to withstand direct sunlight, short periods without water, carbohydrate reserves and mineral nutrient content, and have been inoculated with symbiotic micro-organisms if required (Keys et al., 1996; Wightman, 1999; Stape et al., 2001).

a) Preparation of seed

The seeds are recalcitrant and easily desiccate (Hartati and Kamboya, 2007). This is the case for many tropical and subtropical tree species. There is still limited knowledge on the germination and storage behavior of such tree seeds, especially wild tree species such as the *Diospyros* species. Recalcitrant seeds have high water content, estimated to be in the range of 30-70% at maturity. Recalcitrant seeds germinate rapidly when sown fresh, but are sensitive to desiccation and freezing. Tolerance level depends on the species but normally,

during the storage, the minimal moisture content is 20-35% and minimal temperature is about 12-15 °C for tropical species. This makes them difficult to store. Once desiccation has occurred, it is difficult to re-moisten the seed. Indeed, moisture content needs to be increased without initiating imbibition, or water uptake and germination. Re-moistening by absorption from humid air is thought to be better than submerging the seeds (Mng'omba et al., 2007; Schmidt, 2000).

Seed tests in Indonesia with *D. celebica* showed that fresh seeds sown one day after collection had a germination percentage of about 85%, with germination length from 17 to 65 days. Seeds dried for 3 days did not germinate. Seeds which were not dried, but stored in wet charcoal powder, maintained a germination of 70% after 12 days in storage; after 20 days of storage, germination was reduced to 28%. Another simple storage technique for ebony seeds is to keep them in wet burlap bags at high humidity (80-90% humidity) so that seeds do not dry out. Using this technique, germination percentage was maintained at 50-60% after 2-3 weeks (Hartati and Kamboya, 2007).

The flesh should be removed as it contains germination inhibitors. Soil and fine sand, (3:1) is used for sowing media. Seed is planted horizontally or vertically with radical end down, at a depth of 1-1½ times the thickness of seed. Distance between seed is 3-5 cm (Fern, 2014).

b) Production, care, protection and conditioning of seedlings

A comprehensive review of methods, problems, and development of tropical container nurseries can be found in Agriculture Handbook 732 (Wilkinson et al., 2014). A general account of a container systems used in the tropics is given here.

Black polythene bags and tubes are most commonly used in the tropics (Evans and Turnbull, 2004). However, they have two disadvantages. First, if the seedling is left too long in the container, the seedlings become root bound and roots coil round the inside of the container. Secondly, at planting, the container must be removed or the seedling will be deformed.

In recent years, there has been significant improvement in container design and size. Seedlings of ebonies have long hypocotyl with heavy and large cotyledons, and a strong tap root that is easily damaged during handling (Hartati and Kamboya, 2007; Kiding Allo, 2001; Wallnöfer, 2001). Narrow and deep containers designed for root training and pruning would seem to be the most appropriate for production of high quality ebony seedlings.

c) Growing media

A substrate with good physical and chemical properties is necessary for successful seedling production. It should be a balance of allowing water movement, unimpeded root growth but with the capacity to hold water and nutrients. Soil is used in many locations in the tropics. However, soil-less mixes are becoming increasingly popular, including composted pine bark,

sawdust, coconut fiber, sugarcane bagasse, rice hulls, and peat (Wilkinson et al., 2014). The target range for growing media pH is 5.5 -6.5.

Due to the sensitivity of ebony to desiccation during the germination and nursery phase, first sowing ebony seeds in special germination trays or beds and later transferring, or 'pricking out' to containers is recommended (Hartati and Kamboya, 2007; Kiding Allo, 2001). Germination is usually epigeal, less frequently hypogeal (Wallnöfer, 2001). Normally the germination period ranges from 7 to 126 days (Ng, 1991).

d) Irrigation

Adequate moisture at all times is essential for nurseries in the tropics, even in humid equatorial regions. There are no specific recommendations for watering ebony seedlings. However, most recalcitrant seedling benefit from light, frequent watering (Evans and Turnbull, 2004). Shading is related to watering since it reduces evapotranspiration stress. Although, there are no guidelines for shading schedules for ebony, it requires shading during early growth in the nursery and the need for shade decreases with the age (Hartati and Kamboya, 2007; Seran et al., 1992; Kiding Allo, 2001).

e) Seedling nutrition

Production of healthy seedlings depends on adequate supply of plant nutrients. The need to fertilize depends on the nutrient content of the potting mix, the size of plant and the duration time the plant stays in the nursery. Ebony has no specific fertilization recommendations, but will likely benefit from a general fertility regimen. Phosphorus is usually required as many soils are deficient in this element, and nitrogen encourages leaf and shoot growth. Micronutrients may also be added through foliar applications or slow release fertilizers.

f) Insect and diseases

There is little information on specific pests and diseases of ebony. *Diospyros crassiflora* is attacked by jumping plant lice and defoliating insects (Obeng, 2010). It can be assumed from others *Diospyros* species, namely persimmons, generalist feeder pests such scale, aphids and mealy bugs, will occasionally be troublesome in the nursery. There are likely others. When is occurs, it is important to identify the case of the problem and chose an appropriate control method.

4) Vegetative propagation

The principle reason to utilize vegetative propagation is to take advantage of the ability to capture and fix desire traits found in individual trees (Leakey and Akinnifesi, 2008). Additional rational for cloning ebony species include; the species is a shy seeder (i.e. does not flower and fruit every year or produces only a very small seed crop) (Tsobeng et al.,

2011), the seeds have a short period of viability (Hartati and Kamboya, 2007; Mng'omba et al., 2007) and propagation material is limited (Tsobeng et al., 2011).

Various species of the *Ebenaceae* have been successfully propagated by leafy stem cuttings (Tsobenget al., 2011; Vines, 1960; Lemmens et al., 2012). Successful results have been obtained with different propagation systems, including traditional mist propagators (Tetsumura et al., 2000; Giordani et al., 2013) and low-technology, non-mist propagators (Leakey and Akinnifesi; 2008; CIRAD, 2011).

D. crassiflora coppices well and is amenable to vegetative propagation by leafy stem cutting. The best substrate for rooting was sawdust, with successful rooting rates of more than 41%. Better rooting was observed with longer cuttings. By week 11, the percentage of mortality was highest with shorter cuttings (Tsobenget al., 2011). Thus, the use of stem cuttings as a propagation technique for *D. crassiflora* is recommended (ICRAF; Lemmens et al., 2012).

D) Natural regeneration and native forest management

Ebony groves in native forests of Cameroon give the impression that naturally regenerating seedlings are plentiful after the fruiting season. Nevertheless, this reproduction declines as the stand matures from sapling to pole stages. A preliminary finding from a recent forest inventory reports that timber species require large light gaps for regeneration, and that gaps created through logging are not of the right quality, probably because of intense competition for light and soil resources from shrubs, climbers and pioneers (Thomas and Chuyoung, 2006; Kiding Allo, 2001). The paucity of juvenile timber trees would appear to be a serious problem for future harvest. This poor stand regeneration suggests that environmental conditions are very different now, then in the past when these seedlings were established. While effective silvicultural techniques have been elusive, they are needed to maintain healthy young stands and enrichments planting (Bertault et al., 1995). At the present time, the capacity of the Cameroon Government to implement enrichment planting remains low, and baseline information on the ecological process in these semi-deciduous forest is largely missing (Thomas and Chuyoung, 2006).

A silvicultural experiment conducted in the M'Baïki Forest in Central Africa to test the effectiveness of harvesting and thinning treatments reports that *D. crassiflora* has low natural regeneration, thus recruitment rates were low also (Durrieu de Madron et al., 1998). This rate of seedling recruitment increases with harvesting and is higher when harvesting is followed by a thinning (Table 1). The harvesting consists of felling trees with a minimum harvestable diameter of 80 cm with a yield of 50 m^3/ ha. In the thinning treatment, non-commercial timber tree species with a diameter greater than 50 cm were also removed.

Following the silvicultural treatments, stems replacement is very fast but the volume of individual trees remains, low due to the removal of large trees and competition between the

smaller trees which have been released by thinning. After 10 years, more than 110 % of the total number of stems were replaced, but with less than 30 % of the extracted volume. This indicates large trees are essentially replaced by smaller ones. There is no clear difference between the two silvicultural treatments ((1) harvesting and (2) harvesting + thinning) concerning the recovery rate of the total stand volume (Durrieu de Madron et al., 1998). Nevertheless, the best growth of *D. crassiflora* is recorded for plots which are both harvested and thinned. This indicates *D. crassiflora* responds favorably to thinning and increased light (Table 2).

Table 1. Recruitment rate of *D. crassiflora* by treatment.

	Recruitment rate 1982-1984 (%)	Recruitment rate 1987-1995 (%)		
		Control	Harvesting	Harvesting + Thinning
Diospyros crassiflora	1.50	0.85	1.46	2.07

(Source : Durrieu de Madron et al., 1998)

Table 2. Diameter growth of *D. crassiflora* by time and treatment.

	Diameter growth on 1987-1991 period (cm/yr)			Diameter growth on 1991-1995 period (cm/yr)		
	Control	Harvesting	Harvesting + Thinning	Control	Harvesting	Harvesting + Thinning
Diospyros crassiflora	0.17	0.19	0.33	0.16	0.15	0.21

(Source : Durrieu de Madron et al., 1998)

E) Estimates of rotation age and of growth

Raw growth data for ebony from natural forests or plantations is not widely available. Inevitably, the quantity and quality of published data is low, and is generally inadequate for validation of most growth functions. In addition, mean diameter (DBH) is strongly influenced by stocking density and therefore thinning practices, and site quality (Kriek, 1970). The lack of information on variables such as stand maintenance, seed origins and sampling procedures, limits the precision and accuracy of the data. Further, the data may be derived from stands which have been managed in a way that has reduced its long term productivity. Normally, growth rate varies by age and generally follows a sigmoidal pattern of growth,

with faster growth while the tree is young and slowing as it ages (Evans and Turbull, 2003). However, because of the lack of available data on *D. crassiflora,* only fixed diameter growth rate estimates were available (Owona, 2006; Lemmens et al., 2012).

Rotation age is the planned number of years between the time a stand is established or regenerates, and its final harvest at a specified stage of maturity (Ford-Robertson, 1971). In native forest harvesting concessions in Cameroon and the DRC the minimal diameter at breast height (DBH) is 60 cm for legal harvesting of mature *D. crassiflora* trees, whereas in CAR and Gabon, DBH is 40 cm (Lemmens et al., 2012).

In the best-case scenario (Table 3; Graph 1), with an estimated annual diameter growth of 0.5 cm, a projected rotation age of 120 years was proposed in Cameroon and DRC. In contrast, the estimated rotation age in CAR and Gabon is 80 years.

Based on average annual diameter growth by country, harvest rotation ranges from 80 to 160 years. This is more than three times the average rotation age for native forest management for which rotation age is about 25 years (Doetinchem and Megevand, 2013).

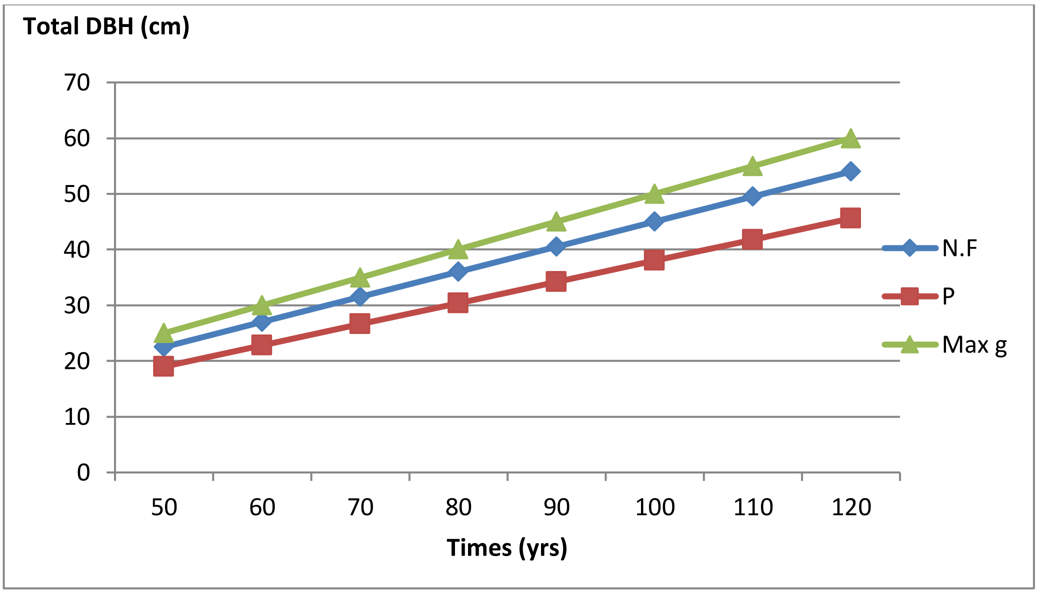
A related species, *D.celebica* although slow growing its annual diameter increment is 0.5 cm/yr (Prajadinata, 2011). Experimental results in Cikampek and Bogor, West Java report annual increment of 1.5 cm/yr for the first 20 years, then decreased to 0.5cm/yr thereafter (Soerianegara, 1987). This suggest condensed rotation ages less of 80 years, may be achievable with improve genetics and silvicultural management.

Table 3. Diameter growth rates of *D. crassiflora* under different management regimes.

Diameter growth rate (cm/yrs)			Time (Yrs)	Total DBH		
N.F.	P	Max g		N.F.	P	Max g
0.45	0.38	0.5	50	22.5	19	25
0.45	0.38	0.5	60	27	22.8	30
0.45	0.38	0.5	70	31.5	26.6	35
0.45	0.38	0.5	80	36	30.4	40
0.45	0.38	0.5	90	40.5	34.2	45
0.45	0.38	0.5	100	45	38	50
0.45	0.38	0.5	110	49.5	41.8	55
0.45	0.38	0.5	120	54	45.6	60

*It should be noted there is no management regime reported in the experimental plantation. Potentially, this is an explanation for why diameter growth rate is lower in plantation than in the native forest. It is likely there was no thinning in the stand the trees growth was slender and tall.

Graph 1. Diameter grow trajectory for *D. crassiflora* growth under different management scenarios.



NF = native forest; P = plantation; Max g = max growth

F) Site selection

Ebony occurs mainly in the lowland, humid tropic and to a lesser extent, in sub-tropical regions of the Old and New worlds. Descriptions of the site preferences for ebonies are largely anecdotal and vary by author and species (Wallnöfer, 2001). It is (highly) likely that site preferences constitute one of the most significant factors in the success or failure of potential future ebony plantings when planted outside their native habitats. There are six factors which have generally proven to be useful discriminators of the region's climatic suitability for growing an particular tree species (Booth, 1996). These factors are used to characterize the climate of a site (Webb et al., 1984):

- mean annual rainfall (mm);
- rainfall regime (uniform /bimodal, winter, summer);
- dry season length (consecutive months less than 40mm rainfall);
- maximum temperature of the hottest month (^oC);
- mean annual temperature (^oC).

The lack of data greatly limits the conclusions that can be drawn about specific site preferences of ebony and *D. crassiflora,* in particular. The natural ecological range of ebony

can serve as a useful guide. Average temperature ranges from 20 °C to 27 °C, rainfall ranges from 1,600 to 3,000 mm/yr, with dry seasons lasting usually 3 months (Table 4.) (Aijbe and Omokhua, 2015; Ouédraogo et al., 2011; Owonda Ndongo et al., 2006; Worbes et al., 2003). Finally, D. *crassiflora* apparently tolerates a wide variety of soil types, ranging from rocky, chalk, clay, loam to sand, but does not tolerant does not tolerate waterlogged soils (Hartati and Kamboya, 2007; Mng'omba et al., 2007; Wallnöfer, 2001).

Table 4. Ecological range of *D. crassiflora* in the Congo basin

	Central Cameroon	**Oban forest reserve (Nigeria)**	**Mbaïki (Central Africa Republic)**	**Arboretum Mbalmayo (Cameroon)**
Average temperature °C)	24	27	20	23
Altitude (m)	600	100-1000		640
Rainfall (mm/yr)	1900	2,500 - 3,000	1738	1600
Humidity (%)		[78-91]		78
Dry seasons	Dec - Feb : 50 mm/month June - Aug : 100 mm/month		Dec - Feb : < 100 mm/month	
	In situ			Ex situ

(Sources : Aijbe and Omokhua, 2015; Ouédraogo et al., 2011; Owonda Ndongo et al., 2006; Worbes et al., 2003)

Further, indicator species, such as coffee, cacao, mahogany, and albizza *(Pararserianthes falcataria)* are humid tropical species of similar climate types, and may be indicative of suitable planting sites for ebony (Evans and Turbull, 2004). Further, Hawaii hosts one native *Diospyros* species (*D.sandwicensis*) lama (Rock, 1974; Little and Skolmen, 1989). Finally, the fruit tree from the Philippines,*D. discolor* (Mabolo) was planted in species trials on Hawaii Island and its growth performance was rated as good (Bryan, 1947).

In Hawaii, these conditions can generally be found at low (below 2,000 ft) elevations sites on the windward and trade wind or rain shadow aspects of the four major islands; Hawaii, Maui, Oahu, Kauai (Juvik and Juvik, 1998). In addition, protection for prevailing trade winds will likely have a significant effect on the potential productivity and success of the ebony planting/plantations.

G) Nutrient requirements

Ebony timber species under review are harvested from native forest stands, so data is unavailable regarding nutrient requirements. However, fertilization data are available for *Diospyros* fruit tree, namely Persimmon (*Diospyros kaki*). This fruit tree is well studied and utilized. These data on fertilization are related to *Diospyros* genus should be considered

carefully because *Diospyros kaki* is grown for fruit and not harvested for its wood. Generally, fertilization regimes for fruit production are significantly more intensive and require different nutrient combinations than timber production. For a summary of persimmons fertilization requirements, see Appendix 2.

Trees, like all plants, require supplies of certain chemical elements for growth. Elements needed in large quantities are 'macronutrients'. These include N (nitrogen), P (phosphorus), K (potassium), Ca (calcium), Mg (magnesium), S (sulfur). Elements needed in minute or trace amounts are, 'micronutrients'. They are Fe (iron), Cu (cooper), Cl (chlorine), Mn (manganese), B (boron), Zn (zinc), Mo (molybdenum). If any of these are in limited supply, or in excessive quantities, tree growth may be impaired. Historically, fertilizer use, has been less important in forestry than in agriculture (Evans and Turnbull, 2004). Intensive nutritional regimes for long term timber production is generally considered uneconomic as fertilizer application is usually needed early in the life of the stand, responses were uncertain, and rotations long.

However, for species conservation, more intensive inputs may be justified. Further, novel strategies will likely need to be developed to ensure sustainability. These strategies may include the use of microsymbiants, such as mycorrhizal fungi and nitrogen fixing bacteria (rhizobia) in combination with leguminous trees such as *Dalbergia* (rosewoods) or *Acacia* (koa) species. These high value, nitrogen fixing forest tree species may serve as mother trees, providing nutrients and shade to mixed ebony plantations, as well as reducing the overall project risk.

H) Regulations (import/export)

Most international transfer of forest tree seed or plant material is subject to restrictions and legislation in both the importing and exporting countries. The purpose of this is to avoid the risk of introducing dangerous seed-borne pests and pathogens into a country where they are not found. *Diospyros crassiflora* is registered on the IUCN red list but not on the CITES list of endangered and threatened species. In Cameroon, it is not considered a threatened species. In this way, ebony plant material is subjected to Cameroon laws regulating exports and the Cites convention is not applicable. Exportation requires inspection by an authorization agency in Cameroon, a certificate of origin, and phytosanitary certification (Asseng Zé, A. and Knoop D., 2009; Loi n° 94/01, c 5, Cameroon).

Diospyros crassiflora is admissible for importation into United States and Hawaii. The following *Diospyros* species must meet US Department of Agriculture Post Entry Requirements: *Diospyros blancoi, Diospyros digyna*, *Diospyros kaki* (*D. chinensis*, *D. roxburgii* et *D. schitse*), *Diospyros lotus, Diospyros texana*, and *Diospyros virginiana* (Merren. A Hao pers. comm).

A final note, the Hawaii Agricultural Research Center holds the all the necessary USDA permits to important a range of admissible plant material from across the globe and has a long track record of successful importation of useful plants into Hawaii.

Conclusions

Ebonies and *D.crassiflora* in particular, are one of the most valuable and rare tropical timbers. Essentially, all ebony timber currently traded is obtained from natural forests. The uncontrolled exploitation of ebony throughout its native range has led to the degradation of many natural stands and raised serious concerns in the conservation community. This has led to its listing as a threatened species. In many areas of its native range, parts of Africa and Asia, ebonies are now considered to be commercially extinct. The development of sustainable management approaches is essential for this species to survive as a timber resource.

These approaches have proved to be elusive. The lack of long-term regeneration following site disturbance associated with logging poses a significant silvicultural challenge for the management of ebony in natural forests. Further refinement of silvicultural techniques to enhance ebony growth, following harvest holds promise.

Given the problems with managing ebony in natural forests, the development of land-use practices such as plantations and agroforestry systems merits serious consideration. Nevertheless, in many respects ebonies are very challenging to grow. Further, there is little evidence of *D. crassiflora* established in plantations. The exception is an experimental plantation at Mbalmayo, Cameroon. Mixed species plantations, where ebony is inter-planted with other high-value hardwoods species such as *Dalbergia* (rosewoods) or *Acacia* (koa) species is an alternative option. These high value nitrogen-fixing forest tree species may serve as mother trees, providing nutrients and shade to the ebony seedlings as well as reducing the overall project risk

Finally, owing to a lack of information, a significant amount of research remains to be accomplished to guide successful nursery management and plantation silviculture for *D.crassiflora*. Development of a strategy for ebony conservation and utilization may include elements of both in-situ and ex-situ genetic conservation. This work is most successful when done within a consortium, composed of government, academic, and industry partners. Nevertheless, as a strategy for ebony conservation and utilization evolves, it will require a long-term commitment and substantial funding with an uncertain outcome.

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Appendix 1: Contact list

Name	Email address	Organization
Merren. A Hao	Merren.A.Hao@aphis.usda.gov	APHIS, USDA
Regis Peltier	regis.peltier@cirad.fr	CIRAD
Charles Doumenge	charles.doumenge@cirad.fr	CIRAD
Philippe Guizol	philippe.guizol@cirad.fr	CIRAD
Dominique Louppe	dominique.louppe@cirad.fr	CIRAD
Olivier Monteuuis	olivier.monteuuis@cirad.fr	CIRAD
Jean Lagarde Betti	lagardebetti@yahoo.fr	ITTO
Christian Mey	meychristian70@gmail	Advanced technician in water and forest and President of alumni ENEF MBalmayo
Zacharie Tchoundjeu	icraf-aht@cgiar.org	Regional coordinator of ICRAF, West and Central Africa. **Tried to contact but no answer**

Appendix 2: Summary of Persimmons fertilization requirements

Persimmons respond well to applications of nitrogen and potassium. A mature tree may require up to 125-250 g of nitrogen and 150–300 g of potassium a year depending on soil fertility and crop load. Split applications of nitrogen and potassium are recommended. As a guide, apply one third of the annual nitrogen and potassium fertilizer before or at bud break and the remainder over summer in two or more applications.
The phosphorus requirement for persimmons is low compared to other deciduous fruit crops. Phosphate uptake by the plant is slow and, if needed, is best applied in autumn and incorporated into the soil. As an annual guide mature trees may need 30 to 40g of phosphorus (Ullio et al., 2003)

Evaluation of annual extirpation by the plant can direct the fertilization technique by indicating the quantities to be returned to the soil (Table 5). It is known that young plants need good availability of nitrogen, while they require only limited quantities of P and K. Over time, the relationship among these macroelements modifies for the increased need of P and K. For plants in full production it is important to have a balanced supply of N, P and K able to maintain a good equilibrium between vegetative and productive activity.

Table 5. Year removal of some mineral elements by persimmon trees in full production (from: Ragazzini, 1983)

Element	N	P_2O_5	K_2O	CaO	MgO
g/tree	501.7	103.63	436.31	508.81	95.41

(Bellini, 2002)

Appendix 3 : Photos

Photo 1 : *Diospyros crassiflora* seeds

(source : http://www.arkive.org/ebony/diospyros-crassiflora/image-G126841.html)

Photo 2 : Removal of flesh to collect seeds of *Diospyros crassiflora*

(source : http://www.arkive.org/ebony/diospyros-crassiflora/image-G126840.html)

Photo 3 : *Diospyros crassiflora* fruit

(source : http://www.arkive.org/ebony/diospyros-crassiflora/image-G126837.html)

Photo 4 : ***Diospyros crassiflora*** **trunk**

(source : http://www.arkive.org/ebony/diospyros-crassiflora/image-G126842.html)

Photo 5 : ***Diospyros mespiliformis*** **fruits**

(source : http://www.prota4u.org/plantphotos/Diospyros%20mespiliformis.full.08.jpg)

Photo 6 : *Diospyros mespiliformis* tree

(source : https://commons.wikimedia.org/wiki/File:Diospyros_mespiliformis_Kruger-NP.jpg)

Photo 7 : Sucker on a root of *Diospyros mespiliformis* tree

(source : Domestication d’arbres à usages multiples :Techniques de multiplication végétative à faible coût. CIRAD. 2011)

Photo 8 : Sucker of *Diospyros mespiliformis* (right) situated at 60 cm from the mother tree (left)

(source : http://bft.cirad.fr/cd/BFT_288_39-50.pdf)

Photo 9 : *Diospyros ebenum* fruit

(source : http://www.biotik.org/india/species/d/dioseben/dioseben_13_en.html)

Photo 10 : *Diospyros ebenum* fruit

(source : https://www.pinterest.com/pin/222365300323010121/)

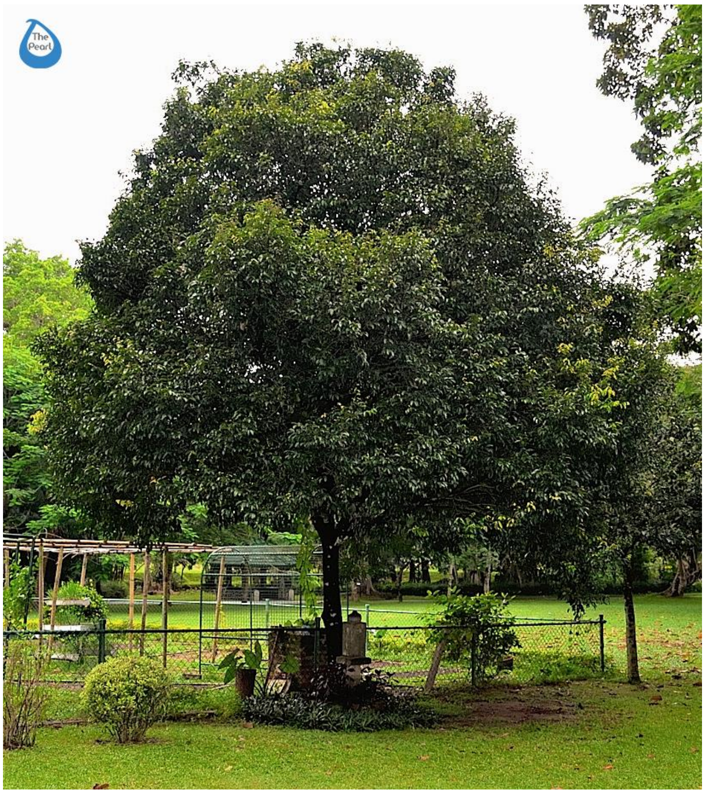

Photo 11 : *Diospyros ebenum* sapling at Gampaha Botanical Gardens

(source : http://thepearl.lk/conserving-the-ceylon-ebony-tree/)

 

Photo 12 : *Diospyros celebica* seeds **Photo 13 : *Diospyros celebica* seeds**

(source : http://abahazis.blogspot.com/2011/05/mengenal-eboni-sulawesi-diospyros.html)

Photo 14 : *Diospyros celebica* seeds

(source : http://www.itto.int/files/itto_project_db_input/2939/Technical/Technical%20Report%20No.1_Review%20of_Management%20and%20Conservation.pdf)

Photo 15 : *Diospyros celebica* nursery

(source : http://www.antarafoto.com/peristiwa/v1200556781/bibit-ebony)

Photo 16 : *Diospyros celebica* plantation

(source : http://www.itto.int/files/itto_project_db_input/2939/Technical/Technical%20Report%20No.1_Review%20of_Management%20and%20Conservation.pdf)

Diospyros celebica logs, ©Debritto.net

Photo 17 : *Diospyros celebica* logs

(source : https://www.wageningenur.nl/upload_mm/7/c/8/e8fe4886-c884-441d-a8e8-64c48f6c70be_diocelf.pdf)

Photo 18 : Persimmon (*Diospyros* kaki) fruits

(source : http://www.onlineplantguide.com/Plant-Details/787/)